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MAIN RING/DOUBLER LOW-BETA INSERTIONS

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Two low-β configurations for the long-straight sections of the main ring and doubler are described below. They are quite similar to the low-β scheme described by Tom Collins[1]. They differ in two essential manners: (1) They are capable of operating at the full desired energy for colliding beam experiments, viz. 250 GeV and 1 TeV for the main ring and doubler, respectively; (2) They require a different quadrupole arrangement than the "standard" long-straight section. Thus, the quadrupoles in a main ring straight section must be removed and replaced with new, longer quadrupoles. For the doubler, the "standard" lattice is taken as that described in a previous TM[2] and this note shows the effect of replacing one of those long-straight sections with one designed to have a variable minimum beta. In practice, one might use this as the standard bridge, thus giving tunable flexibility to all of the straight sections as well as the possibility of initial running with high superperiodicity.

Presented below are schemes for the insertion of one low-β section into the main ring and doubler lattices, along with the various quadrupole strengths, etc., needed in order to keep the horizontal and vertical tunes at 19.4. These insertions can be tuned, adiabatically, from a nearly normal long-straight section down to a minimum beta of 1 meter and 4 meters for the main ring and doubler, respectively, while not exceeding current quadrupole gradient limits of 240 kG/m - 6.096 kG/in and 1011.8 kG/m - 25.7 kG/in for the two rings.

Main Ring Insertions

The geometry of the main ring insertions is shown in Fig. 1. It consists of replacing the four inner quadrupoles which make up the long-straight doublet with two, 15.5 foot quads, and having four independent power supplies, Q_1 - Q_4, as shown. This reduces the available free space in the long straight by some ±2 meters and also reduces the available space between the doublet quads. The rest of the ring is left unchanged. The new quadrupole length has been chosen so as to keep within the above mentioned gradient limit at 250 GeV. Should one desire to go to a different maximum energy, or should the spacing between these two quadrupoles prove inadequate for correction elements, etc., the lengths and spacing can be changed without significantly affecting the results.

Table I lists the required quadrupole strengths to reach various minimum betas. In all cases alpha at the crossing center is zero so the beta at the center is the minimum beta. Because of the increased phase advance across the special long straight, the currents in the normal quadrupole surplus must be reduced in order to maintain the tunes at 19.4. These are also listed in Table I. Table II shows some of the results of one insertion tuned to various β^*'s. The insertions have been tuned so as to preserve the present lattice mismatch. Thus, outside the insertion, defined in Fig. 1, the α's and β's of the machine remain unchanged. The phase advance between elements does change due to the decrease in tune of the normal part of the ring, but this is fairly small, on the order of 5-10% between $\beta^* = 60$ m and $\beta^* = 1.1$ m. The major change is in the dispersion function η. η normally oscillates around the ring, due to inherent mismatch, with a magnitude ranging from ~(5.9 m , 1.2 m). The inclusion of one low-β straight section increases this to, for $\beta^* = 1.1$ m

(13.3 m, -5.5 m). This will cause problems in beam size, the radial feedback pickup, and other things, but is essentially unavoidable. Effectively, the only way to affect η is by changing dipoles, and this is prohibited by the geometry of the tunnel. In the case of two or more low-β straight sections, the η oscillation can be greatly influenced through the relative positions of the low-β sections and their particular β^*'s, although only a few such schemes have been looked at in any detail.

One other effect of a low β^* is the increase of beam size within the insertion. Table II lists the maximum η and β's for various tunes and corresponding energies for each β^* in order to keep the beam size no larger than that at injection. In all but the first two examples given, these maximum values occur within the new, 15.5' quadrupoles. A few typical plots of the lattice parameters across the insertion are shown in Figs. 2-4.

Doubler Insertion

The insertion for the doubler is essentially identical to that for the main ring. Its geometry, relative to both the main ring and Tom's doubler lattice, is shown in Fig. 1. It consists again of using four separate power supplies and replacing the inner doublets with longer quadrupoles, in the case, 14.5 feet. This again reduces the total free space by $\sim \pm 2$m. In addition, however, the next outer-most quadrupole has been exchanged for a normal cell quadrupole. Because the quad's length can only increase in one direction - toward the medium or mini-straight and not back toward the closest dipoles - the optical center has been shifted from the geometrical center. In Tom's lattice, the doubler center was already ~10 inches from the main ring's center, and in the low-β section it has been shifted over about another 10 inches. Thus the β^*'s talked about are not at the

crossing center but some half meter away. This causes some slight increase in beam size according to the formula

$$\beta = \beta^* + \ell^2/\beta^*$$

where ℓ is the displaced distance. Thus, for $\beta^* = 4$ m, the beam size at the crossing point is given by $\beta = 4.02$ m.

There is, in addition, a slight beam mis-match because the spacing from the doublet to the next outermost quadrupole is not identical for the up- and downstream sides. This occurs in order to keep the downstream mini-straight at least a meter long for correction elements, etc. This causes less than a 1% beta oscillation outside the insertion.

In all other respects, the doubler with one low-β insertion is virtually identical to the case for the main ring described above, and has the advantage that the lattice parameters do not get as as in the main ring case since the β^* can be larger by the energy large rates. Tables III and IV list quadrupole gradients and beam parameters for various β^*'s at 1 TeV.

References

1. T.L. Collins, "Easy Low-Beta for the Main Ring, TM-649, March 1976
2. T.L. Colling, "A Doubler Magnet-Lattice with Long Straight Sections", TM-678, July 1976

Table I. Main Ring Low-β Quadrupole Gradients

(kG/m) (250 GeV)

β*	F-bus	D-bus	Q_1	Q_2	Q_3	Q_4
60	150.8009	-150.6700	-135.1927	208.4797	-119.1903	98.7436
40	150.1745	-150.0440	-144.2438	233.5935	-140.4735	119.2226
20	149.3691	-149.2391	-136.1143	247.8643	-176.8406	169.0099
10	149.0387	-148.9089	-108.3608	224.4009	-196.8149	204.0468
5	148.8872	-148.7576	-60.4160	116.7973	-205.3870	223.0307
2	148.3954	-148.2692	45.1424	81.7030	-208.6095	234.7556
1	147.9924	-147.8633	136.8946	69.9129	-210.9185	236.9445

Note: Q_1 has both signs and goes smoothly through zero

Q_2 at β* = 20 m has a gradient >240 kG/m, and so must be ramped through β* = 20 m and not left at it.

Table II. Main Ring Low-β at 250 GeV

β^*	η^*	η_{max}	β_{max}	Energy to keep beam size same as at 8 GeV
60 m	2.28 m	6.68 m	123.7 m	8 GeV
39.8	1.41	7.02	125.5	8
19.8	0.71	8.06	141.7	10
9.9	0.62	9.03	251.6	18
5.0	0.70	10.17	503.2	36
2.0	0.88	13.18	1257.5	90
1.1	0.95	22.43	2461.8	178

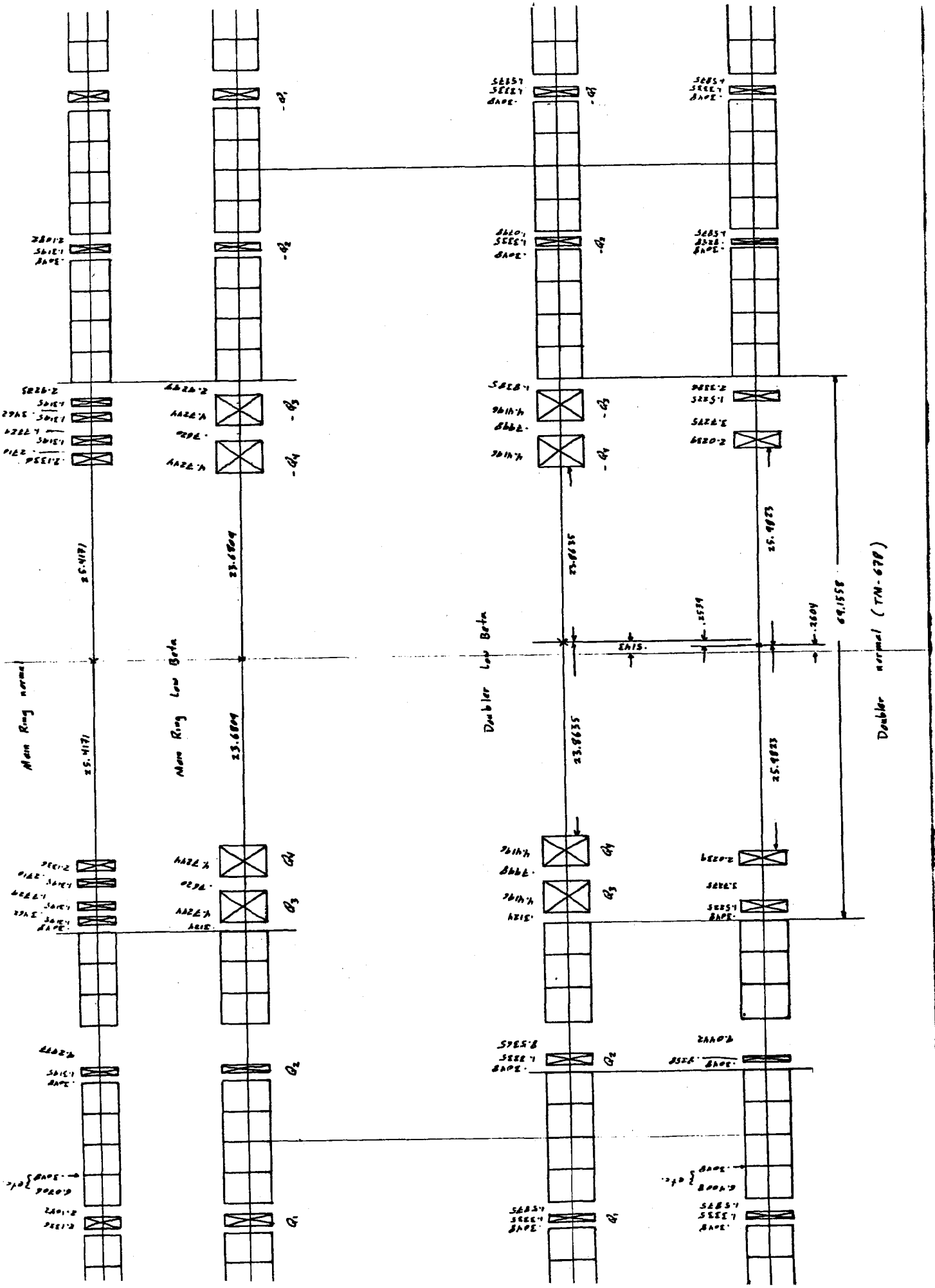
For $\beta^* \lesssim 20$ m, both β_{max} and η_{max} occur within the special insertion quads. Outside of the long straight insertion, as defined in Fig. 1, the lattice functions (α's and β's) are virtually identical to those with no insertion, and the dispersion oscillates with, at $\beta^* = 1$ m, a range of (13.3 m, -5.5 m). For larger β^*'s, the range of oscillations is less, being, at $\beta^* = 60$ m, (6.7 m, 0.8 m).

Table III. Doubler Low-β Quad Gradients at 1 TeV
(kG/m)

β^*	Q_F	Q_D	Q_1	Q_2	Q_3	Q_4
60	951.6785	-950.8209	-847.8887	811.4227	-518.0873	433.8087
40	948.0680	-947.2134	-905.3072	909.7154	-610.0571	521.1480
20	943.8085	-942.9574	-855.3378	963.2492	-767.3192	731.8785
10	942.1047	-941.2550	-681.5922	867.8926	-852.5600	881.6296
4	940.7660	-939.9174	-243.2470	537.6301	-895.2341	981.5136

Table IV. Doubler Low-β at 1 TeV Insertion Parameters

β^*	η^*	η_{max}	β_{max}
60.0	2.22	6.89	121.8
39.8	1.39	7.14	122.0
19.6	0.76	8.08	142.4
10.0	0.68	8.94	244.1
4.1	0.77	10.51	597.4


Main Ring normal
Main Ring Low Beta
Doubler Low Beta
Doubler normal (TN-678)

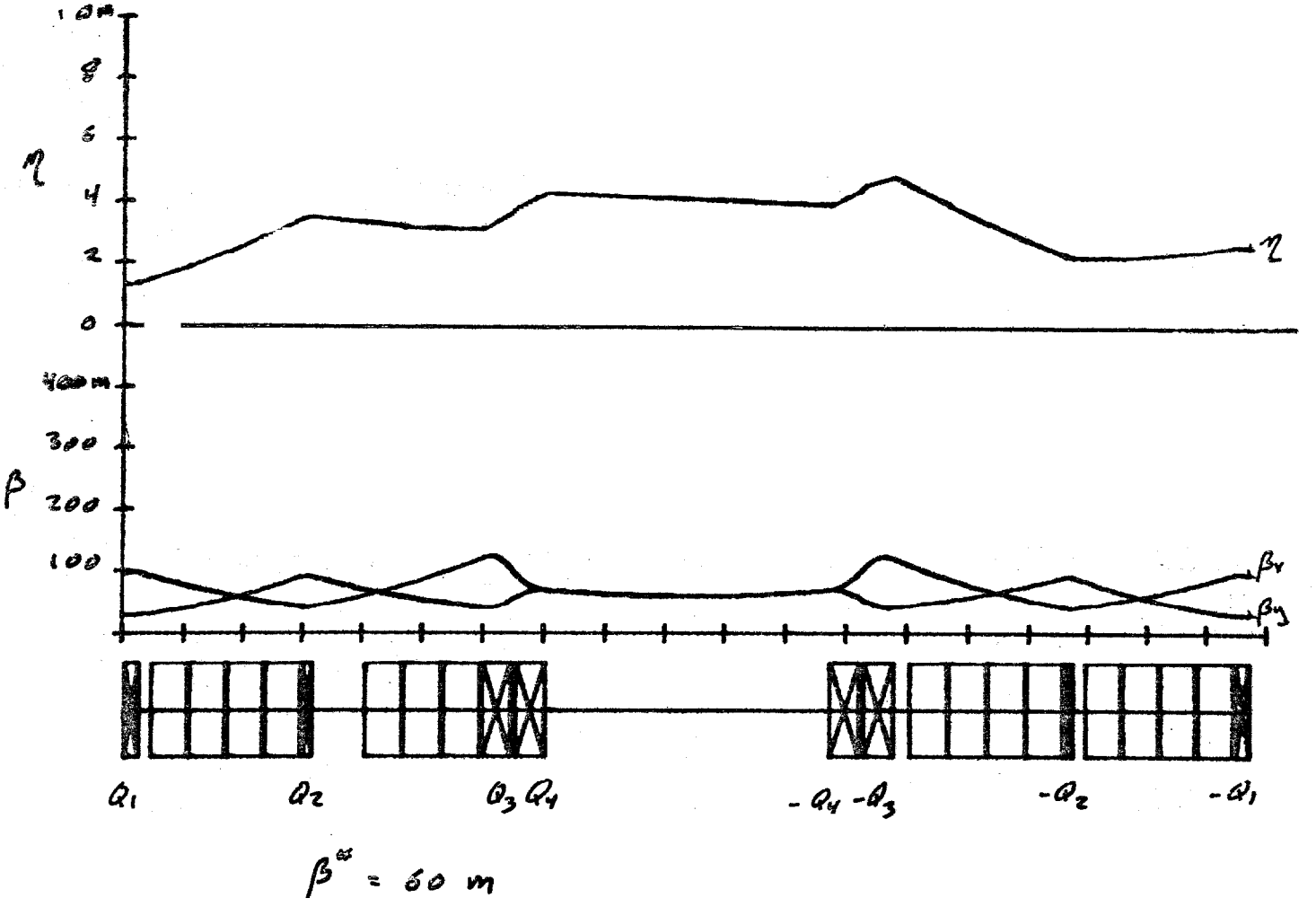


Fig. 2 Main Ring Low-β

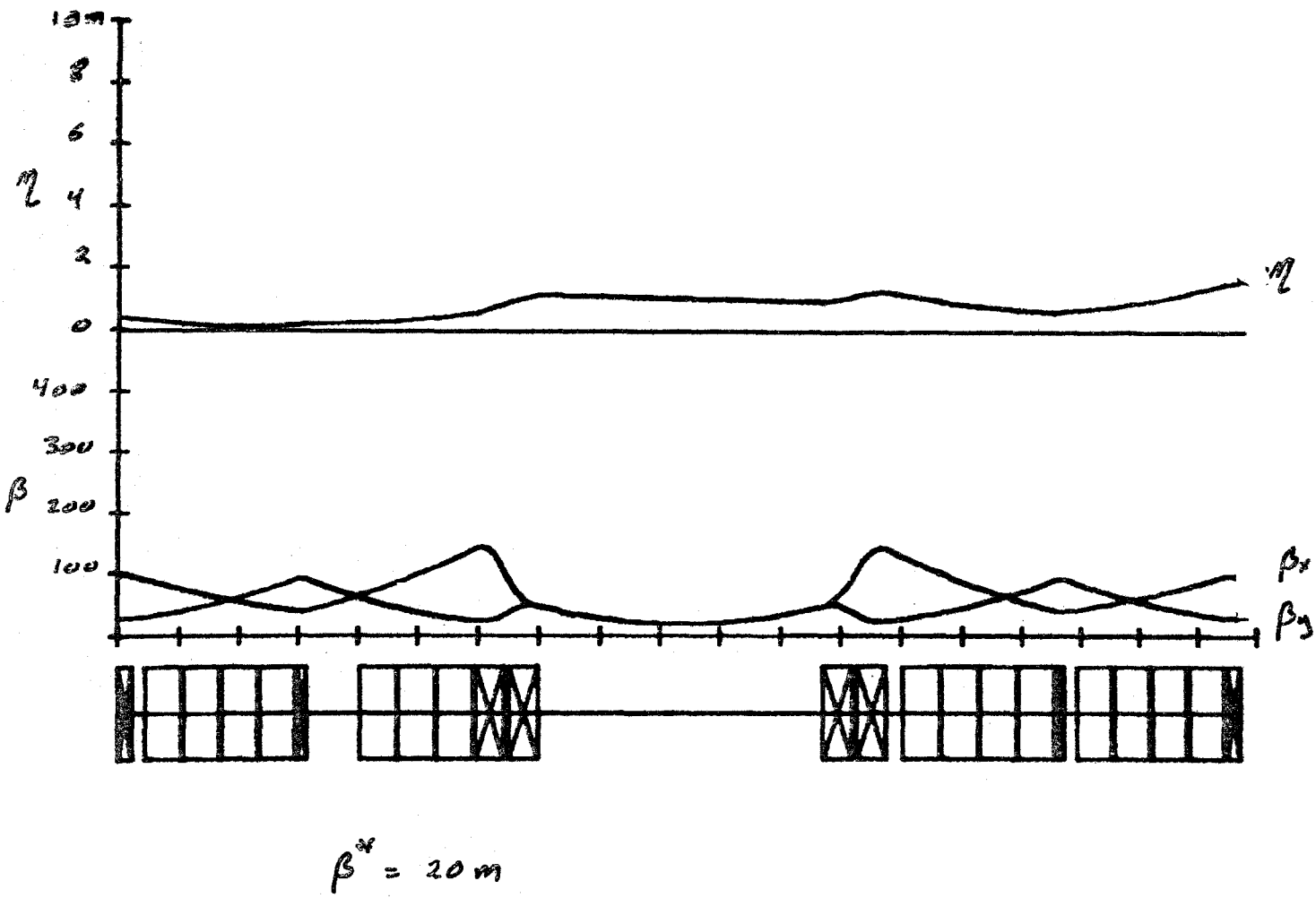


Fig. 3 Main Ring Low-β

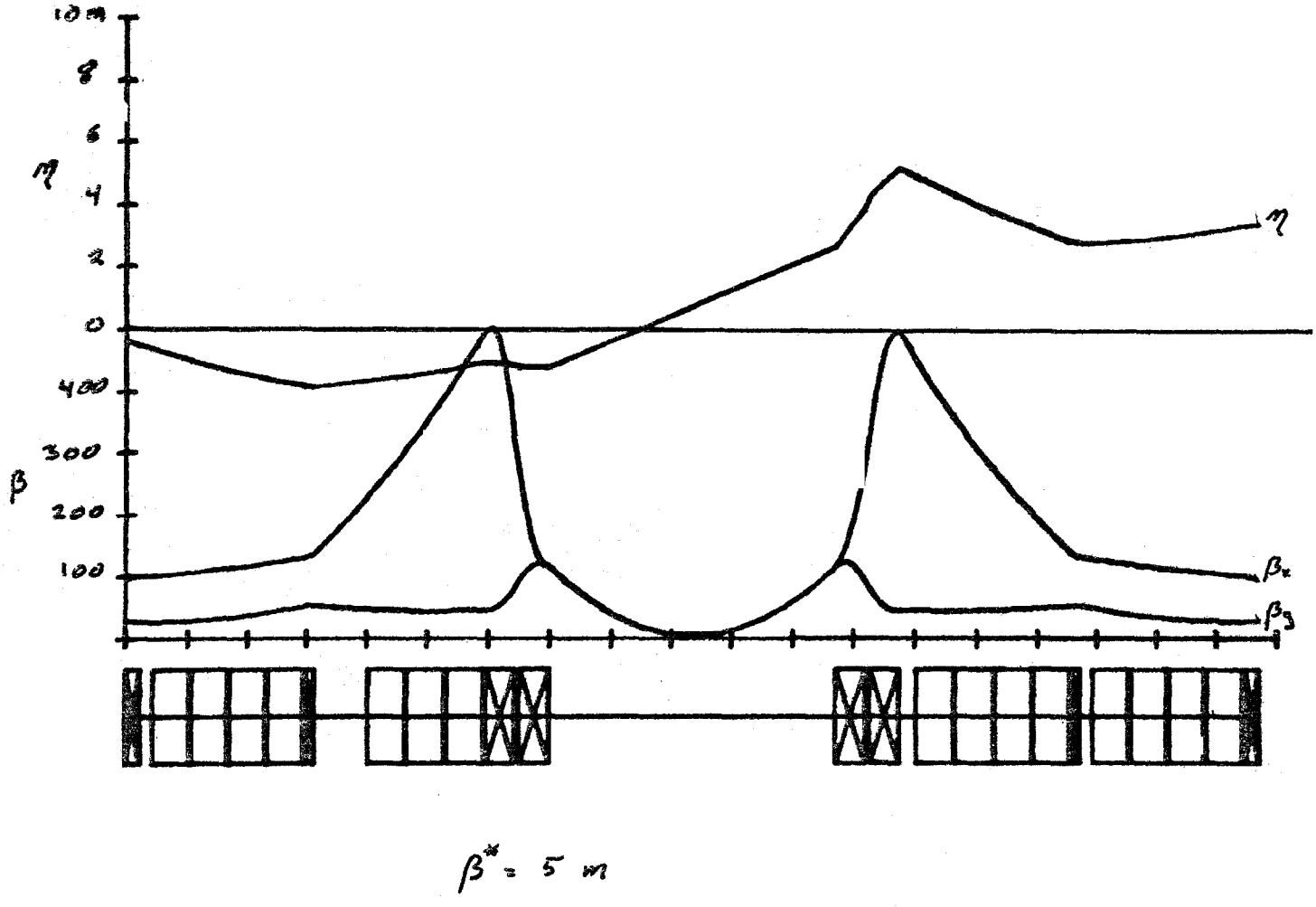


Fig. 4 Main Ring Low-β